

# QCD Analysis of Diffractive DIS at HERA

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## Abstract

The QCD analysis of deep inelastic diffractive scattering at HERA is performed assuming the dominance of the "soft" pomeron exchange and simple, physically motivated parametrization of parton distributions in the pomeron. Both the LO and NLO approximations are considered and the theoretical predictions concerning the quantity  $R = F_L^D/F_T^D$  for diffractive structure functions are presented.

## Résumé

Une analyse de la diffusion diffractive profondément inélastique à HERA est présentée, basée sur la dominance d'un poméron "doux" et une simple, physiquement motivée paramétrisation des distributions des partons dans le poméron. Les approximations des logarithmes dominants et au-delà des logarithmes dominants ont été considérées et les prédictions théoriques pour la quantité  $R = F_L^D/F_T^D$  pour les fonctions diffractives de structure sont présentés.

The main aim of this paper is to analyse the diffractive processes in deep inelastic  $ep$  scattering at HERA [1, 2, 3], assuming that they are dominated by a "soft" pomeron exchange with the pomeron being described as a Regge pole with its trajectory

$$\alpha_P(t) = \alpha_P(0) + \alpha'_P t, \quad (1)$$

where  $\alpha_P(0) \approx 1.08$  and  $\alpha'_P = 0.25 \text{ GeV}^{-2}$  [4]-[10]. Different description of these processes based on the "hard" pomeron which follows from perturbative QCD has been discussed in [11]-[14].

The diffractive structure functions have the following factorizable expression :

$$\frac{dF_{2,L}^D(x_P, \beta, Q^2, t)}{dx_P dt} = f(x_P, t) F_{2,L}^P(\beta, Q^2, t). \quad (2)$$

The function  $f(x_P, t)$  is the so called "pomeron flux factor" which, if the diffractively recoiled system is a

single proton, has the following form [10]:

$$f(x_P, t) = N x_P^{1-2\alpha_P(t)} \frac{B^2(t)}{16\pi}, \quad (3)$$

where  $B(t)$  describes the pomeron coupling to the proton and is parametrized as below [10]

$$B(t) = 4.6 \text{ mb}^{1/2} \exp(1.9 \text{ GeV}^{-2} t). \quad (4)$$

The normalization factor  $N$  was set to be equal to  $\frac{2}{\pi}$  following the convention of refs. [4, 6, 10]. In addition we have slightly increased  $\alpha_P(0)$  in the flux factor  $f(x_P, t)$  (3) up to  $\alpha_P(0) = 1.1$  [3].

The functions  $F_{2,L}^P(\beta, Q^2, t)$  are the pomeron structure functions with the variable  $\beta$  playing the role of the Bjorken scaling variable for the  $\gamma^*(Q^2)$  pomeron inelastic "scattering".

In the region of large  $Q^2$  the pomeron structure function  $F_2^P$  is expected to be described in terms of the QCD improved parton model and is related in the

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conventional way to the quark distributions  $q_i^P(\beta, Q^2, t)$  in the pomeron:

$$F_2^P(\beta, Q^2, t) = 2 \beta \sum_i e_i^2 q_i^P(\beta, Q^2, t), \quad (5)$$

where  $e_i$  are the quark charges (note that  $q_i^P = \bar{q}_i^P$ .) The above formula is given in the leading logarithmic approximation of perturbative QCD in which the pomeron longitudinal structure function  $F_L^P = 0$ .

At first we shall specify the details of the parton distributions in the pomeron at the reference scale  $Q_0^2 = 4\text{GeV}^2$ .

At small  $\beta$  both the quark and gluon distributions are assumed to be dominated by the pomeron exchange

$$\begin{aligned} \beta q_i^P(\beta, Q_0^2, t) &= a_i^P(t) \beta^{1-\alpha_P(0)} \\ \beta g^P(\beta, Q_0^2, t) &= a_g^P(t) \beta^{1-\alpha_P(0)} \end{aligned} \quad (6)$$

The functions  $a_i^P(t)$  and  $a_g^P(t)$  can be estimated from the factorization of pomeron couplings [4, 7, 9]:

$$a_i^P(t) = r(t) a_i \quad a_g^P(t) = r(t) a_g, \quad (7)$$

where the parameters  $a_i$  and  $a_g$  are the pomeron couplings controlling the normalization of the small  $x$  behaviour of the sea quark and gluon distributions in the **proton** i.e.

$$\begin{aligned} xq_i(x, Q_0^2) + x\bar{q}_i(x, Q_0^2) &= 2 a_i x^{1-\alpha_P(0)} \\ xg(x, Q_0^2) &= a_g x^{1-\alpha_P(0)} \end{aligned} \quad (8)$$

and the function  $r(t)$  is:

$$r(t) = \frac{\pi}{2} \frac{G_{PPP}(t)}{B(0)} \quad (9)$$

The coupling  $G_{PPP}(t)$  is the triple pomeron coupling and its magnitude can be estimated from the cross-section of the diffractive production  $p + \bar{p} \rightarrow p + X$  in the limit of large mass  $M_X$  of the diffractively produced system  $X$ . We neglected the (weak)  $t$  dependence of the function  $r(t)$  and have estimated its magnitude from the recent Tevatron data [16] as  $r(t) \approx r(0) = 0.089$ . The parameters  $a_i$  were estimated assuming that the sea quark distributions in the **proton** can be parametrized as:

$$xq_i(x, Q_0^2) + x\bar{q}_i(x, Q_0^2) = 2 a_i x^{1-\alpha_P(0)} (1-x)^7 \quad (10)$$

and fixing the constants  $a_i$  from the requirement that the average momentum fraction which corresponds to those distributions is the same as that which follows from the recent parametrization of parton distributions in the proton [17, 18]. The momentum sum rule has also been used to fix the parameter  $a_g$  i.e. we assumed

$$xg(x, Q_0^2) = a_g x^{1-\alpha_P(0)} (1-x)^5 \quad (11)$$

and imposed the condition that the gluons carry 1/2 momentum of the proton. We extrapolated the pomeron dominated quark and gluon distributions in the pomeron (see (6)) to the region of arbitrary values of  $\beta$  by multiplying the factor  $\beta^{1-\alpha_P(0)}$  by  $1-\beta$  [7].

We have also included the term proportional to  $\beta(1-\beta)$  in both the quark and gluon distributions [7]. The normalization of this term in the quark distributions has been estimated in [6] assuming that it is dominated by the quark-box diagram with the non-perturbative couplings of pomeron to quarks. In this model one gets:

$$\beta q^P(\beta, Q_0^2) = \frac{C\pi}{3} \beta (1-\beta), \quad (12)$$

where  $C \approx 0.17$  [6]. We found that the fairly reasonable description of data can be achieved provided that the constant  $C$  is enhanced by a factor equal to 1.5. We have also assumed that the relative normalization of the quark distributions in the pomeron corresponding to different flavours is the same as that of the sea quark distributions in the proton [17, 18]. Finally the normalization of the term proportional to  $\beta(1-\beta)$  in the gluon distribution in the pomeron has been obtained by imposing the momentum sum rule. Following the approximations discussed above we have neglected the  $t$  dependence in those parton distributions.

As the result of the estimates and extrapolations discussed above the parametrization of parton distributions in the pomeron at the reference scale  $Q_0^2 = 4\text{GeV}^2$  looks as follows:

$$\begin{aligned} \beta g^P(\beta, Q_0^2) &= (0.218 \beta^{-0.08} + 3.30 \beta) (1-\beta) \\ \beta u^P(\beta, Q_0^2) &= 0.4 (1-\delta) S^P(\beta) \\ \beta d^P(\beta, Q_0^2) &= 0.4 (1-\delta) S^P(\beta) \\ \beta s^P(\beta, Q_0^2) &= 0.2 (1-\delta) S^P(\beta) \\ \beta c^P(\beta, Q_0^2) &= \delta S^P(\beta), \end{aligned} \quad (13)$$

where the function  $S^P(\beta)$  is parametrized as below

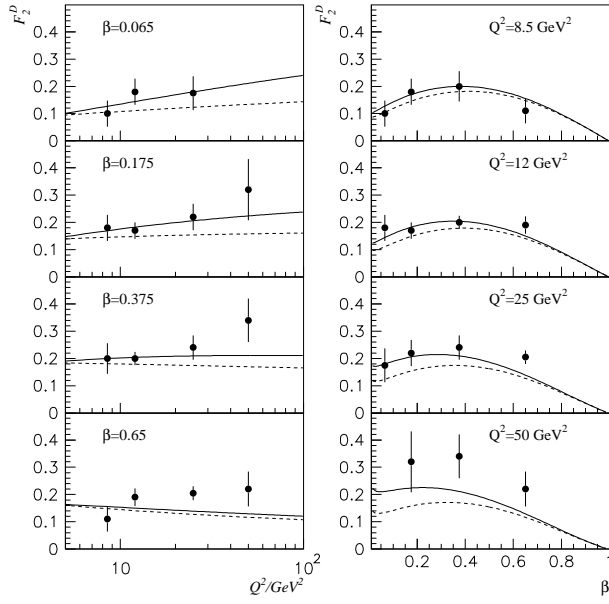
$$S^P(\beta) = (0.0528 \beta^{-0.08} + 0.801 \beta) (1-\beta) \quad (14)$$

and  $\delta=0.02$  [17, 18]. The analysis of the pomeron structure functions based on different parametrizations of parton distributions in the pomeron has recently been presented in refs. [9, 19].

The parton distributions defined by eqs.(13,14) were next evolved up to the values of  $Q^2$  for which the data exist using the LO Altarelli-Parisi evolution equations [20, 21] with  $\Lambda = 0.255 \text{ GeV}$  [18]. In Fig.1 we show our results for the quantity:

$$F_2^D(\beta, Q^2) = \int_{x_{PL}}^{x_{PH}} dx_P \int_{-\infty}^0 dt \frac{dF_2^D(x_P, \beta, Q^2, t)}{dx_P dt} \quad (15)$$

with  $x_{PL} = 0.0003$  and  $x_{PH} = 0.05$  [3], plotted as the function of  $x_P$  for different values of  $\beta$  and  $Q^2$ . We



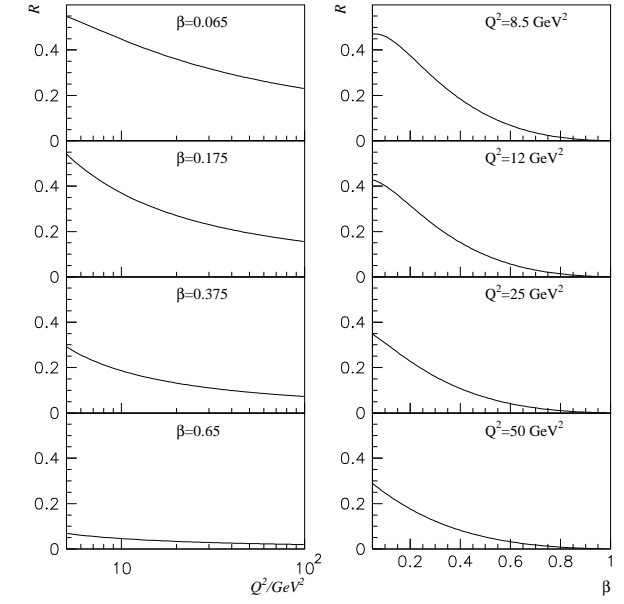
**Figure 1.** Theoretical predictions for diffractive  $F_2^D(\beta, Q^2)$  and their comparison with the data from HERA (solid lines). Dashed lines show predictions when there are no gluons at the initial scale  $Q_0^2$ .

see a very good agreement with the recent data from H1 collaboration at HERA [3]. Dashed lines in Fig.1 show  $F_2^D(\beta, Q^2)$  computed when gluons were neglected at the initial scale  $Q_0^2 = 4\text{GeV}^2$ .

We have also performed the NLO QCD analysis in order to be able to consistently introduce the quantity  $R = F_L^D(\beta, Q^2)/F_T^D(\beta, Q^2)$  where  $F_T^D(\beta, Q^2) = F_2^D(\beta, Q^2) - F_L^D(\beta, Q^2)$  and  $F_L^D(\beta, Q^2)$  is defined in analogy to (15). We compared the NLO and LO results for  $F_2^D(\beta, Q^2)$  from Fig.1 and found that both approximations lead to similar predictions. In Fig.2 we show our results for  $R$ . The longitudinal diffractive structure function is driven mainly by the gluon distribution in the pomeron and a large amount of gluons (see 13) implies that  $R$  can reach 0.5 for  $\beta \leq 0.1$ .

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**Figure 2.** Theoretical predictions for diffractive  $R$  plotted as the function of  $Q^2$  (for fixed  $\beta$ ) and the function of  $\beta$  (for fixed  $Q^2$ ).

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